Planning for an environment-friendly car

Udo Mildenberger, Anshuman Khare *

Universität Mainz FB03, Lehrstuhl für ABWL und Produktionswirtschaft, Jakob-Welder-Weg 9, 55099 Mainz, Germany

Abstract

During the process of developing a new product, consciously or unconsciously, a number of decisions are made that affect the environment, thus making a company responsible not only for the technical performance but also for the "environmental performance" of a product. This research paper broadly speaks about this development process and lists the various tools available to the modern decision maker for balancing the ecological, economical and technological aspects of production.

The focus of this paper is on the environmental issues in the automobile industry and environmental impacts presently associated with the automobile life cycle. The paper reviews existing tools and opportunities for reducing these burdens in the future through decision-making by industry and other stakeholders.

The paper ends with a very latest example from the German automobile industry on the assumption that this automobile (SMART from MCC AG), in the present context, is perhaps an outcome of a very vigorous development process where the impact of the product outside the automobile sector was considered. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Life Cycle Management (LCM); Life Cycle Assessment (LCA); Automobile life cycle; Life cycle cost tools

1. Preamble

During the process of developing a new product, consciously or unconsciously, a number of decisions are made that affect the environment, thus making a company responsible not only for the technical performance but also for the "environmental performance" of a product.

Decision makers (managers and engineers) would argue that it is extremely difficult to ascertain today whether a product would be considered environmentally friendly in ten years' time. Fig. 1 attempts to roughly present a timeframe over which a decision is valid in different parts of the world depending on their economic standard.

The German car-maker BMW offers a more concrete example of how long range the effects of a decision today are. It takes about 3–4 years to design a car and it is manufactured over a period of 7–8 years. These vehicles would be in use for about 10–12 years. In all,

a decision taken today will have its effect for about a quarter of a century. Maybe more, when one considers the long term repercussions of irresponsible disposal of waste (BMW, 1998).

It is true that of the products that are on the market today many were not considered to be harmful to the environment when they were designed. On the other hand, R&D staff have already done much — often unconsciously — for the environment. Electric ovens, refrigerators and freezers today need about 30 percent less energy than 20 years ago; in many machines the power per kg of weight has been increased significantly, more precise machinery allows a more efficient use of materials, to quote just two examples (North, 1992).

In order to systematically consider the environmental aspects, the R&D methodology has to balance the ecological, economical and technological aspects of design and production. It may be given the task to review and further develop existing products and processes. This concerns:

- the design;
- the applied materials;
- the manufacturing process; and

* Corresponding author. Tel.: +49-6131-392007; +49-6131-393005.
E-mail address: khare@mail.uni-mainz.de (A. Khare)

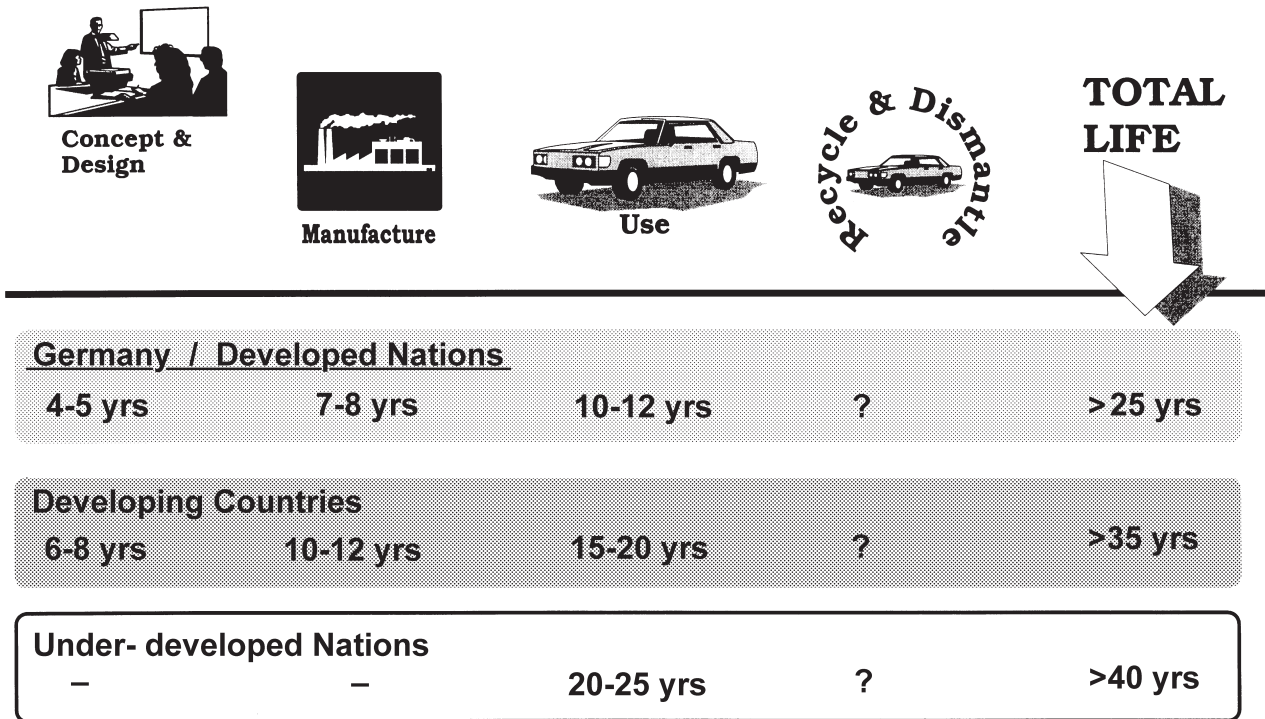| Concept & Design	Manufacture	Use	Recycle & Dismantle	TOTAL LIFE
Germany / Developed Nations				
4-5 yrs	7-8 yrs	10-12 yrs	?	>25 yrs
Developing Countries				
6-8 yrs	10-12 yrs	15-20 yrs	?	>35 yrs
Under- developed Nations				
–	–	20-25 yrs	?	>40 yrs

Fig. 1. Life of a decision taken today.

- the product's performance characteristics (e.g. energy consumption).

This paper attempts to present environmental issues in the automobile industry and environmental impacts presently associated with the automobile life cycle. The paper reviews existing tools and opportunities for reducing these burdens in the future through decision-making by industry and other stakeholders.

2. Analysis of product life cycle

Fig. 2 outlines the research and development methodology for environment friendly products. The process starts with the setting up of R&D aims and tasks which include a review of existing products and processes with environment related criteria. It is at this stage that an attempt could be made to conceive new environment benign products and processes.

Once R&D's aims and tasks have been defined, an analysis of the present system follows. This may comprise the existing products of a company or may be extended to the products of competitors. It should start with an environmental impact analysis for the product's entire life cycle. It relates the total cycle of a product's life to the environmental impact caused in each phase. Traditionally, R&D staff have limited themselves to only considering the phase of active use of product. It is only recently that the whole life cycle of the products forms

part of R&D specifications. The use of renewable materials and "clean technologies" is of importance in all phases of the life cycle. The design of the product should be accompanied by the conception of the recycling procedure.

Besides this environmental impact analysis on the product's life cycle, a number of other analytical methods can be carried out. An industrial engineering tool known as **value analysis** or **value engineering** (Wellenreuther, 1996) is also particularly suited to making better use of materials and therefore saving not only money but also natural resources. Value engineering analyses the functions or "value" of each element of a product. As a result, products are simplified and reduced to their essential parts.

3. Specification for green products

The next stage of R&D methodology deals with the generation of specifications (requirements list), for both products and processes. In such detailed lists the requirements a product or process has to fulfil must be spelled out for each phase of the life cycle. Minimum requirements are often defined by government regulations or the relevant national or international standards, e.g., norms of the International Standards Organization, ISO. Requirements to be given special attention are:

- avoidance of scarce, non-renewable materials;

R&D Tasks and Aims
Review existing products and processes
   with environment related criteria
Conceive new products and processes
   using renewable material and "clean"
   technology

**Measuring and control of
performance After sales services**
Long-term tests
Consumer / retailer acceptance
   of product
Review recycling procedure

Analysis of present system
Environmental impact analysis
   of product life cycle
Value engineering
Technical analysis
Market analysis

**Implementation of
chosen alternative**
Project management
Clean technology

**Generation of specifications
(requirements list)**
Integration of environment related
   requirements
Requirements for total life cycle
Environmental standard setting

Evaluation of alternatives
Include environment related evaluation
   criteria
Product liability
Testing procedures
Certification procedures
Cost Benefit Analysis
   (*Kosten Nutzen Analysen*)

1. 2. 3. 4. 5. 6. 7.

**Creation of products and process alternatives
(a) ideal solutions (b) real solutions**
Bionics
Brainstorming
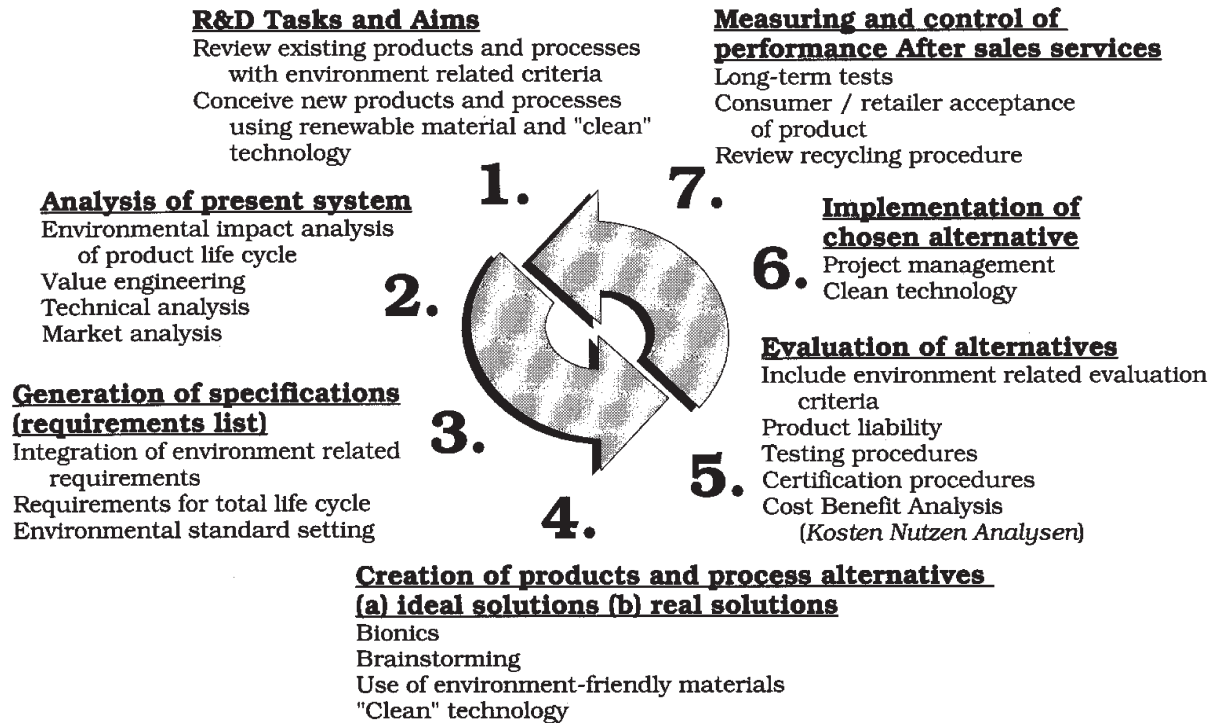Use of environment-friendly materials
"Clean" technology

Fig. 2.   R&D methodology for environment friendly products (Based on North, 1992).

- recycling of the product;
- energy efficiency of the product;
- avoidance of hazardous substances;
- minimization of energy, water consumption and polluting substances during the production process;
- durability of product.

4. New solutions

After such "green" specifications have been set, the core process of R&D work begins: the creation of new ideas for products and processes. In the first stage — using brainstorming techniques — ideal solutions for a given problem should be developed. From these solutions a number of real problem solutions are derived.

In order to develop environment-friendly products, there is much to be learned from nature, which makes the most effective use of its resources. The discipline, known as **bionics**, incorporates principles or processes of nature into engineering. Bionics, for example, studies the reasons why trees are so resistant to wind, how birds fly, or how natural membranes function to clean water.

The use of alternative materials and designs is a further potential to be explored by R&D staff. It is this phase of creation that the manufacturing processes of the products under discussion should be roughly defined and the resulting by-products analyzed.

5. Evaluation and testing

Once the product and process alternatives have been developed, they need to be evaluated to see if they really meet the set specifications. Evaluation in this context must consider the technical, ecological aspects along with the economical aspects. Methods to help decision makers to choose between alternative solutions are *Kosten-Wirksamkeits* and *Kosten-Nutzen-Analysen* (Cost Benefit Analysis).

6. Implementation

After a prototype or a pre-series have been successfully manufactured and tested in the R&D laboratories or workshops, the responsibility for implementation as well as measurement and control of performance will be handed over to Industrial Engineering or Production.

The after-sales services as, for example, the implementation of a recycling procedure, may be commissioned to sales or a specialized engineering department, or even a subcontractor. These arrangements, however, depend largely on size and the organizational structure of the enterprise.

Apart from integrating environmental considerations into each step of the R&D methodology (Fig. 2), there are other measures which can assist a company with innovating products and processes faster than their competitors, for example by:

- shortening development cycles;
- flexible research programs to keep up with the fast-changing agenda;
- promoting creativity (e.g. by assigning environmentally committed staff to R&D project or by incorporating outside researchers or members of environmentalist groups into R&D teams);
- integrating an environment-related component into existing company programs (e.g. quality and productivity improvement programs, value engineering); and
- environment related information into R&D information and design systems (for example, into Computer Aided Design (CAD) systems).

7. The automobile industry

The automobile industry is the largest manufacturing enterprise in the world and is one of the most resource-intensive industries of all major industrial systems. Further, the global automotive manufacturing is oligopolistic in structure, dominated by a relatively small number of large producers.

The awareness of the overall environmental impact in the automobile industry has been growing as European and U.S. regulations, e.g. for vehicle emission, have become more stringent. To rank the level of awareness is difficult because different automobile companies lead in different areas. Generally, the automobile industry as a whole tends to work on similar issues, including improving aerodynamic shapes and lowering weight. Manufacturing processes are also being cleaned up, with special attention being given to the reduction of emissions and material of concern. Procedures are now aimed at ensuring that factory waste is recovered for further processing, and an increasing portion of R&D budgets is being allocated to the development of alternative fuels, and electric and hybrid vehicles. Vehicle manufacturers are placing increasing emphasis on recycling, including: developing new technologies to facilitate the use of recycled materials; designing vehicles with recycling in mind; designing and specifying components that can be made out of recycled materials; and increasing the use of recycled materials. For better handling of end-of-life vehicles, European and U.S. auto-makers have built up cooperative partnerships to establish a recycling infrastructure, to set up pilot disassembly facilities, and to develop disassembly manuals. Car manufacturers have started stating explicit fuel economy targets for their vehicles and have set environmental standards for their service stations.

The awareness of Life-Cycle Management tools and approaches is growing among the European and the American automobile industries. This is expressed in terms of studies and projects conducted to examine the life-cycle impacts of different materials, processes, and concepts in business practices. All automobile manufacturers are active in conducting internal Life-Cycle Assessment (LCA) and are involved in ongoing cooperative LCA projects in Europe (EUCAR) and the US (USCAR). They have launched "Design for the Environment" training programs for product and manufacturing engineers within their respective organizations and for their suppliers. To a lesser extent, manufacturers are active in environmental accounting.

8. The automobile life cycle

The life cycle of an automobile begins with concept and design and concludes with retirement (end-of-life scrapping); this section is a reflection on the total life cycle of an automobile.

Today, a vehicle consists of approximately 15 000 parts. Steel, iron, glass, textiles, plastic, and non-ferrous metal dominate automobile construction. They account for more than 80% of the material used in today's vehicles. A common trend in the material composition of a car is toward increasing the use of light-weight materials, especially numerous types of plastics and light metal alloys (such as aluminum and magnesium).

The environmental impacts and concerns that arise from the acquisition and processing of virgin resources that serve as input for automotive material include the substantial consumption of resources (material and energy). In addition, copious amounts of energy are consumed in heating, cooling, and producing millions of tons of steel, aluminum, plastic, and glass. Processing these materials involves a variety of heavy metals, toxic chemicals, chlorinated solvents, and ozone depleting chemicals. The largest contribution to non-hazardous waste among the life-cycle stages is mining waste (e.g. overburden) associated with energy generation and iron ore production. The residue from auto shredding operations is the second largest contributor.

Beside the painting and coating operations, the metal casting operations are the main manufacturing operations where air emissions occur. More than half of all releases and transfers of pollutants originate from the painting and coating operations. Furthermore, the paint shop is one of the main consumers of primary energy within the manufacturing process along with iron casting. The largest solid waste streams generated by an automobile assembly plant are wastewater treatment sludges, waste oil, plant trash, and scrap metal.

The utilization of an automobile accounts for approximately 80% of the total primary energy consumption of the life cycle of an automobile. Most of the CO_2 and CO (CO production in a catalyst equipped car is relatively smaller) emissions are released during the utilization.

VOC emission during the use of the automobile (e.g. exhaust and evaporation) is greater than that generated in any other life-cycle stage. The second largest contributor to VOC emission is automobile painting. Besides the resource consumption when running a vehicle and the necessary infrastructure (e.g. highways, service- and gas stations), the maintenance and service operations contribute significantly to the environmental effects of automobile use.

Environmental impacts in the scrapping stage consist of waste generated during different processes and energy depletion (or loss) resulting from these activities. The impact is strongly dependent on the material composition of vehicles and the infrastructure in place to process the vehicles. The changing material content of automobiles presents a difficult issue: on the one hand, greater use of light-weight material such as plastics improves fuel efficiency and reduces air and/or exhaust emissions. On the other hand, design changes that increase the amount of plastics result in lower levels of recyclability.

Opportunities for environmental improvement exist during each life-cycle stage of an automobile. This paper suggests that the manufacturer focus on regulation, policies, agreements, and process and design improvements that influence either one stage or the entire life cycle.

For example, European and American regulations and policies that impact different stakeholders in the automobile life cycle differ in numerous ways; examples are:

- In the US taxes on gasoline are considerably lower than in European countries. This results in much lower gasoline prices in the US than in any European country.
- The USA relies on a regulation to discourage the manufacture and sale of fuel-inefficient vehicles. It introduced the Corporate Average Fuel Economy (CAFE) in 1975 requiring that producers of domestic and imported cars achieve certain mandated average fuel-economy standards on a fleet-wide basis.
- Nearly all European countries have introduced "End-of-Life Vehicle" (ELV) policies with targets for the increased reuse and recycling of ELV parts and materials, and the reduction of waste disposed in landfills. In the United States no national and state legislation on ELV recycling or management has been passed.

Significant changes in the material and process selection and management are necessary to reduce the overall environmental impact throughout the entire life cycle of an automobile.

Fig. 3 summarizes programs, partnerships, and policies that encourage life-cycle management; concepts and tools in various stages of development that can facilitate life-cycle; and various life-cycle management approaches from academia, research institutes, and industry (Kuhndt, 1997).

9. Life-Cycle Management

The development of Life-Cycle Management (LCM) strategies and principles was undertaken because other strategies, for example, focusing on a single life-cycle stage, sometimes yield sub-optimal results. Reducing environmental impacts at specific points in a product life, for example, reducing energy consumption in the usage phase, may be of little or negative value if other changes also occur such as increasing energy consumption in manufacturing and recycling.

LCM is broadly defined as:

- A framework to redesign product systems to reduce overall environmental impacts.
- A decision-making activity by multiple stakeholders in different stages of the life cycle of a product.
- A framework that is based on information about product life cycle (e.g. physical flows of mass and energy, monetary flows).

Industry and government can establish several types of programs, partnerships, and policies that encourage LCM as shown in Fig. 3.

Decisions are reached by an iterative process involving various tools and resulting in action. They may be guided by concepts such as "Industrial Ecology" (Frosch, 1996), "Cleaner Production" (Rolfe et al., 1995), "Eco-Efficiency" (NRTEE, 1997; Schmidheiny and Zorraquin, 1996), "The Natural Step" (Robert et al., 1995), and "Factor 10".

To capture a broad picture, one can focus on some generic types of life cycle tools, including:

- analysis tools, such as Life-Cycle Assessment (LCA) and Life-Cycle Cost (LCC) tools that provide the environmental profile of product and process prioritizing areas for improvement, and on
- improvement tools, such as Life-Cycle Design (LCD) tools that implement improvement throughout the design methodology.

During the past years, the automobile industry has performed on its own or in cooperation with different parties (e.g. their suppliers, trade associations, universities, etc.) a number of Life Cycle Assessments to compare materials (e.g. aluminum vs steel), processes (e.g. water-based painting vs. powder painting) and concepts (e.g. electric vehicle vs internal combustion vehicle). Often the result of these studies do not show a clear advantage of one over the other material, process, or concept. Therefore, it might be more suitable to use these
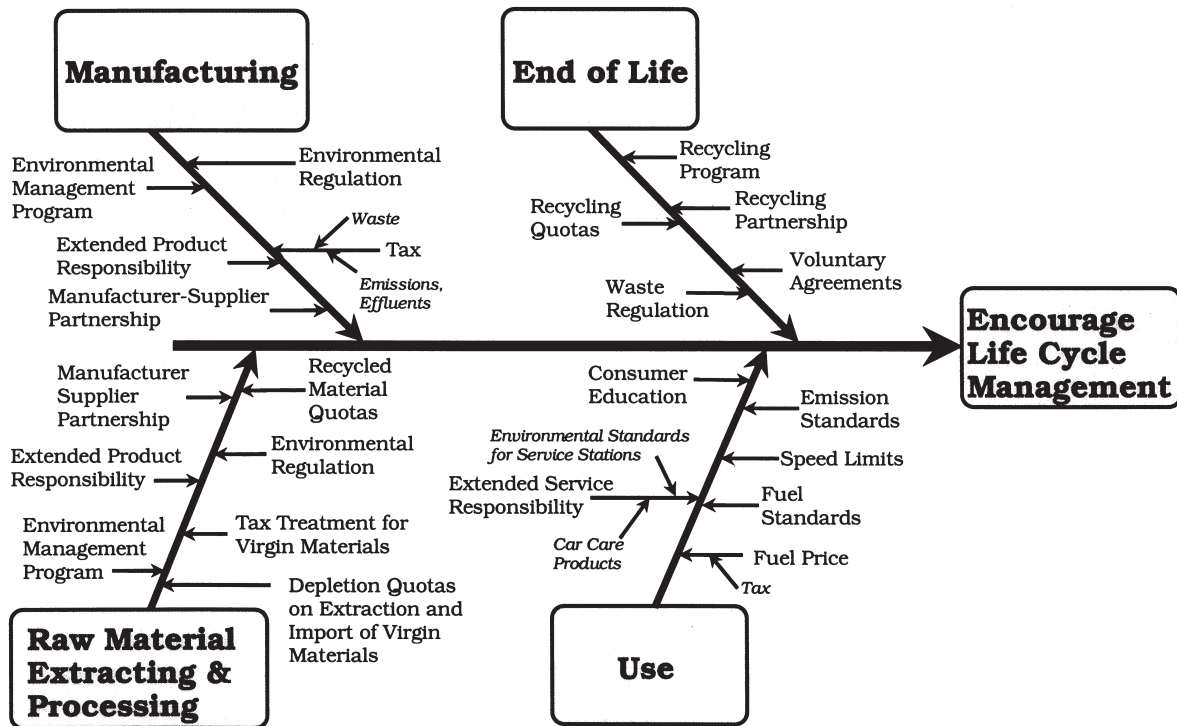
Fig. 3.   Programs, partnerships and policies that encourage Life-Cycle Management.

results to develop optimization strategies for the analyzed materials, processes, and concepts.

Although significant progress has been made towards standardizing LCA, results can still vary significantly. Such discrepancies can be attributed to differences in system boundaries of different industries, rules for the allocation of input and outputs between product systems, data availability, and different conversion models for translating inventory items to environmental impacts. Plus, one has to keep in mind not only the impact of the product, but also the after affects which are often felt in the sectors outside the primary industry (automobile industry in this case).

Life-Cycle Management is needed for all decision-making processes in order to avoid shifting the burden from one medium (for example, water consumption, pollution, etc.) to another or one life-cycle stage to another. The compromises made cannot be evaluated or it cannot be deducted that the action would have an impact on another process up ahead or on another industry. To avoid tradeoffs in material and process selection, decisions should be based on the results of studies using LCM tools. These results should include the *environmental profile* (e.g. resource-intensity, toxicity, recyclability) and *cost profile* (internal and external cost) of different materials throughout the life cycle.

The environmental profile can be analyzed with LCA; but to support LCM, the availability and quality of material, energy, solid waste, and emission data cur-

rently limit the application of LCA for each life-cycle stage.

Therefore, a more integrated approach to selecting material and processes with minimal environmental impact should involve cooperative relationships between different players in different life-cycle stages to cover this data gap. Through a collaborative effort of suppliers, automobile manufacturers, and end-of-life managers and based on LCA findings, LCC results and other information (e.g. reparability and durability), guidelines and checklists for life-cycle design (LCD) should be developed. These guidelines and checklists will, then, be available to design engineers at the manufacturer and at the supplier to optimize existing and new products and processes.

The idea can be presented broadly if one thinks of information sharing networks. Just like there are no boundaries to the environmental problem, there would be no boundaries to the information generating and sharing processes.

Unlike traditional cost management tools, **Life-Cycle Cost tools** (LCC tools) are arranged to register the costs of a product during all life-cycle stages. In this way, they consider not only the direct production costs, but also the indirect (environmental) costs during consumption and disposal of a product. The LCC tools are, therefore, able to optimize the total efficiency of a product. For environmental aspects this is very important, because the level of the environmental costs are determined to a large

extent in the design phase; in the consumption and disposal stage, there are only small possibilities to influence these costs. Unfortunately, because the current market system does not reflect external costs, a design that minimizes the environmental burden may appear less attractive than an environmentally inferior alternative. Therefore, industry will mainly optimize life-cycle costs with the means of reducing direct and indirect costs. Governments can, then, complete this calculation and act on behalf of the public through assessing the cost and burden to society.

The design phase of products and processes presents the greatest opportunity for applying LCM tools and, therefore, should be a focal point for establishing partnerships. However, besides this, further stakeholder initiatives are necessary. Examples are:

- Consumers have a major role in reducing the environmental impacts associated with ownership and operation. Governments, in partnership with automobile manufacturers, can launch more programs to educate customers, for example, in driving behavior and proper maintenance of the vehicle.
- Automobile manufacturers should vigorously and sincerely pursue goals and targets for future fuel consumption of their vehicle fleet.
- Automobile manufacturers should share responsibility not only for the product (the car) itself, but also for service-related issues (e.g. car care products).
- Suppliers, manufacturers, and government should take responsibility for further development of alternative concepts, such as alternative vehicles, alternative fuels, and alternative transport systems.
- Worldwide information generating and information sharing networks and partnerships are necessary to improve the situation in end-of-life management.

A more sustainable automobile life cycle will also require re-thinking the whole value chain of the product system and envisioning how one can create new services with minimized environmental impact. If, for example, the current common purchase of the product, "automobile", were to be replaced by meeting the mobility needs through the more resource-saving variants (reasonably priced and convenient modes of public transport, for example), most stakeholders would look for different means of providing services than is common today. For example, with suitable attitude changes, the automobile industry could focus on, e.g.

- eco-leasing and eco-rent, whereby the automobile is no longer to be purchased by the consumer but rented for usage over a certain period;
- car-sharing and car-pooling, whereby the automobile industry sells mobility.

Incidentally, the first option is available today in some parts of the world, but not very popular as the consumers often opt for ownership for financial flexibility and other less tangible reasons. The second option is also not much practiced and needs promotion. The reasons are not only economical but also intermingled with individual behavior patterns and social factors.

The government could focus on *global system optimization*, e.g.

- providing alternative transportation modes that are more efficient than the automobile (specially in terms of pricing, punctuality and reliability);
- providing infrastructure that reduces the demand for mobility by bringing living, shopping, and business areas closer together (however, this issue in city-planning remains a debatable issue due to pros and cons of having everything at one place).

Complex manufactured products like an automobile do not offer straightforward opportunities for product-oriented assessments due to their direct and indirect impacts on other sections of the economy. However, this product does have a good potential for life cycle-based improvements. The development of a sustainable (environmentally effective) automotive industry will depend on using the output of tools, such as life-cycle analysis, life-cycle costing, and life-cycle design, to analyze and to improve the management of resources. From material selection through processing and fabrication to recovery and recycling, working relationships, partnerships among different stakeholders are necessary for reducing the total environmental impact of producing and using personal transportation.

10. The Daimler-Benz example

Daimler-Benz, one of Germany's leading car manufacturers, has attempted to address the environmental concerns of the EC as well as that of others with the new Micro Compact Car (MCC) AG (Daimler-Benz, 1998). This has been widely welcomed. The story below is adapted from the Daimler-Benz's Environmental Newsletter 7/98.[1] It is perhaps one of the most comprehensive examples today of a manufacturer moving out of its own boundaries to provide the customers with an eco-friendly solution for mobility.

In August 1998, experts from the German Traffic Association selected the SMART (the name of the MCC AG car) as the winner of the 1998 ecology check. The reasons why the new city coupé was able to top the list

---

[1] Daimler Benz concedes in the *Privacy Statement* that there is a possibility of some inaccuracies relating to technical data. The authors have also not questioned the accuracy as the intent of the paper is to focus on the managerial and non-technical issues.

of environmental automobiles included low pollutant emissions, low fuel consumption and a comprehensive mobility concept.

10.1. System concept

The city coupé, Smart, has a fuel consumption of 4.8 liters per 100 kilometers, measured in a standard, three-part mixture of urban cycle (city traffic) and constant speed operation (country and highway traffic). However, the Smart is designed primarily for city traffic (where it proves sufficient as a two-seater — on journeys to work, for example, cars only carry an average of 1.2 occupants). On city trips of this nature, the fuel consumption of the Smart is about 5.8 liters per 100 kilometers. With carbon-dioxide emissions of less than 120 grams per kilometer, its two gasoline engines (33 and 40 kW) can be considered as particularly clean.

Daimler-Benz, however, has not only addressed the issues related to emissions and fuel consumption, but the whole subject of environmental compatibility is considered in its entirety keeping in mind the responsible attitude toward ecologically designed products. Whether vehicle development, factory premises, vehicle production, utilization or future recycling, environmental protection decisively influences all phases of product life cycle.

Such an environmentally conscious approach even played a role in the establishment of the factory premises in Hambach in Lorraine in 1996; for example, exclusion of environmentally harmful building materials. Construction workers were trained to separate waste products on a regular basis. This was not an easy task given the cultural and language problems: 1000 workers from France, Portugal and Algeria were present on the construction site, and Daimler-Benz did not stop at simply distributing brochures. A total of 300 tons of building waste, hardware, concrete as well as material used for facades and shells was separated rigorously. That is equivalent to 60% of all building waste generated annually by the company. All buildings are free of formaldehydes and CFCs, while the facades consist of a paneling made of a raw material (Trespa) originating from European woods. Smartville is the name of the 70-hectare industrial estate (13 hectares of which consist of built-up land), which blends harmoniously with the Lorraine countryside. An ecological landscaping concept was prepared for this purpose with attention to the expansive green patches at the parking lot in front of the factory gates, where young mirabelles, apples trees and a diversity of meadow flowers grow.

10.2. Production concept

The environment is enjoyed by roughly 1600 people, many of whom are not MCC employees. Roughly 12 system partners and providers of logistics services have set up business premises in Smartville.

As a result, it has been possible to introduce an inter-site environmental management system. All suppliers are listed in a basic manual for environmental protection. This is the first time that such a measure has been implemented for an industrial estate. The success of the specified environmental measures, which are obligatory for all parties, is checked regularly by a specially appointed work group.

Another task of this work group is to continuously adapt the management system to changing environmental conditions and laws, and optimize related measures.

The just-in-time production concept alone makes it profitable for suppliers to establish themselves directly on the production site in Smartville. Main modules such as the chassis, axle assemblies and cockpit (instrument clusters and dashboard assemblies) are assembled by the system partners at their own workshops.

These modules are transported via conveyor belts to the final assembly halls, thus eliminating the need for long supply routes (Fig. 4):

- The Tridion passenger compartment cell and cockpit are connected together at the "engagement station".
- The car body, running gear, and drive unit are coupled at the "wedding station".
- The windows, roof and cockpit are added at the "furnishing house".
- Decorative elements and accessories are fitted in the "embellishment studio".
- Doors, hatches and bumpers are installed in the "design shop".
- A short test run and various functional checks are performed in the "fitness studio".
- After that, the vehicle is rolled into the quality shop for final inspection.

10.3. Easily recyclable design concept

The modular design of Smart allows each vehicle to be fully assembled in just 4.5 hours. The developers attached the highest priority to an easily recyclable design. If an automobile can be assembled quickly, then conversely, it should be possible to dismantle it easily too. This has been MCC's approach from the beginning. For example, the plastic paneling has a simple press-fit. This also allows the colors of the Smart to be altered quickly by interchanging the body panels, should the owner desire a different look.

An easily recyclable design also has other advantages, such as materials that can be re-used. The tubes, covers and interior fittings are made of materials like polyethylene and polypropylene. Furthermore, only pure plastics (refers to plastics that are used in a way so that it is easy

The different parts
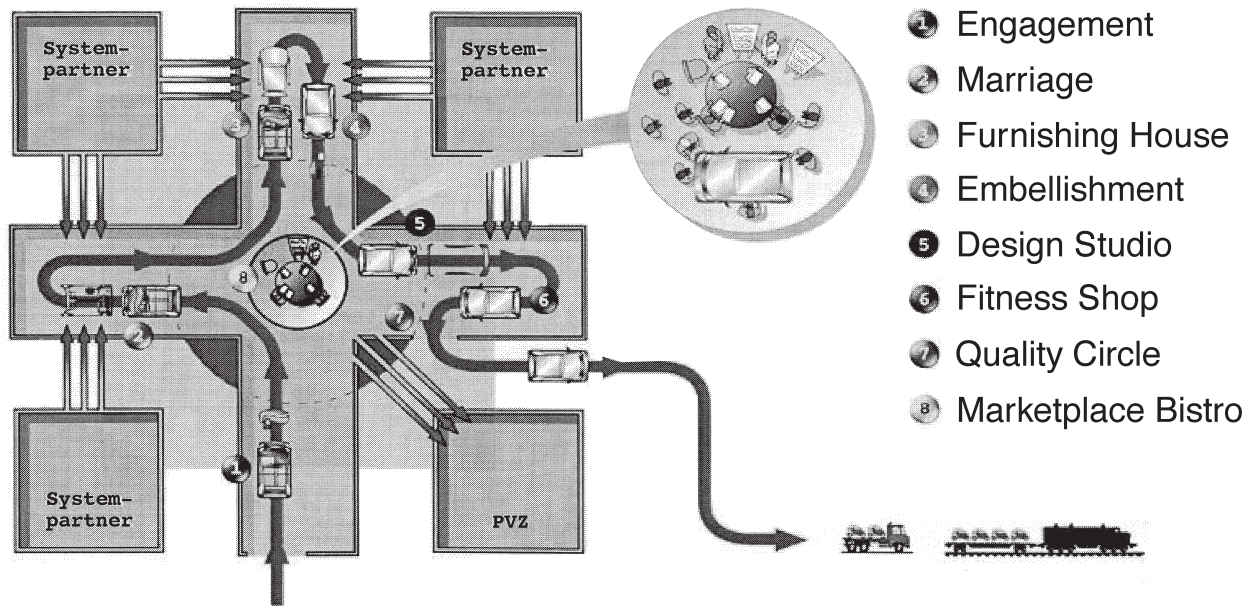## of the production system "SMART-PLUS"

Fig. 4.   The micro compact car AG from Daimler-Benz (Ref: http://www.daimler-benz.com).

to separate while dismantling and easy to recycle) and metals have been used. The joint sealings on the body and the underseal of the Smart are free of PVC.

The entire chassis of the vehicle is powder-painted. The compact design of the Smart allows the powder-based paint to be applied evenly.

Priming is performed without lead. The subsequent painting process does not involve the use of heavy metals like cadmium or chrome. In addition, no solvents are emitted, nor are any special waste products such as paint sludge generated. Needless to say, excess powder is collected and re-used.

In order to save raw materials, recyclates are employed in the production of the two-seater wherever possible. Accordingly, the interior paneling of the doors consists of 100% recyclates. With the total proportion of recyclates as 15%, the Smart is 95% recyclable.

10.4. Mobility concept

However, the easily recyclable design is not the only aspect which led the jury of the German Traffic Association to put this small car on top of its environmental list.

What impressed the experts most of all, was the mobility concept of the Smart. The "Smart plus" service package offers drivers a pool of different types of vehicles. For example, Avis offers economical terms for renting small vans in order to move house, or off-road vehicles to go on vacation.

Together with regional transport authorities, plans have been made to offer the Smart in conjunction with the related public transport facilities. "Smartmove tours" is currently being tested in several large cities. For instance, when train passengers arrive at their terminus, they could use their train tickets to cheaply rent a city car on-location. Airline passengers could use their flight ticket to book a Smart at their destination airport.

10.5. Recycling concept

Hand in hand with the development of a Smart dealership network, a "Smart Center Recycling" system will be offered throughout Europe. This system is intended to allow the removal of residual material from the Smart center. Needless to say, this material is passed through a recycling process.

However, MCC's ecological product responsibility extends even further: the modular design alone is a guarantee that dismantling can be performed economically once the Smart's service life is over. In this way, the modular concept allows the completion of material utilization cycles.

10.6. Summary

With all these measures, MCC has been able to demonstrate an unprecedented degree of responsibility regarding the design and production of an environmen-

tally compatible product. It is a feat in keeping with its corporate philosophy and something that sets an example in the automobile industry.

The comprehensive nature of MCC's environmental protection campaign ensures that the Smart, which was developed in line with state-of-the-art technology, will achieve the highest possible degree of environmental compatibility both during and after its service life. With its dynamic environmental management system, which is continually undergoing improvement, MCC has laid a cornerstone for environmentally friendly, individual mobility.

The result is impressive. The Smart has a high recyclable content not only in the vehicle interior and exterior, but also in technically complex sections such as the cockpit, where a recyclate proportion of more than 10% has been achieved. The use of identical thermo-plastic substances as well as easy dismantling ensure optimal recycling properties. This module also replaces 20 conventionally designed components, thus saving additional resources.

Acknowledgements

References

BMW Umweltbericht 1997/98 (1998), Munich, Germany (in German).

Daimler-Benz's Environmental Magazine 7/98 (1998), Internet Version (October 1998) available at Daimler-Benz website.

Frosch, R.A., 1996. Industrial ecology: Adapting technology for a sustainable world. Environment 37, 16–24.

Kuhndt, M., 1997. Towards a Green Automobile. In:. IIIEE Publications, Lund, Sweden.

National Round Table on the Environment and the Economy, 1997. Measuring eco-efficiency in business: developing a core set of eco-efficiency indicator, backgrounder. NRTEE, Ottawa.

North, K., 1992. Environmental business management — An introduction. Management Development Series No. 30, International Labour Office, Geneva.

Robert, K.H., Daly, H., Hawken, P., Holmberg, J., 1995. A Compass for Sustainable Development. The Natural Step: Overview and Discussions. New Dimensions, Boston, US.

Rolfe, H., Legard, R., Christie, I.R., 1995. Cleaner Production in Industry: Integrating Business Goals and Environmental Management. Brookings Institute, London.

Schmidheiny, S., Zorraquin, F., 1996. Financing change: The financial community, eco-efficiency, and sustainable development. World Business Council for Sustainable Development, WBCSD Cambridge. MIT Press, MA.

Wellenreuther, H., 1996. Innovation mit Hilfe der Wertanalyse. In: Staudt, E. (Ed.) Das Management von Innovationen. Frankfurter Allgemeine Zeitung, Frankfurt, pp. 160–170. (in German).

Udo Mildenberger works as a Research Scientist at the "Lehrstuhl für Allgemeine Betriebswirtschaftslehre und Produktionswirtschaft" at Johannes Gutenberg University Mainz (Germany). He teaches Cost Analysis and Cost Management, Production and Technology Management and System Theory (with special focus on System Dynamics). His doctoral research was in the field of inter-organizational production networks. In addition to this, his research interests lie in the field of modern industrial organizations, learning organizations, and environment related production management from a more theoretical system theory and resource based viewpoint. He has delivered lectures at the Banking University, Frankfurt, Germany and at the Warsaw School of Economics, Warsaw, Poland. He has published one book and about 30 research papers and articles in Germany and abroad.
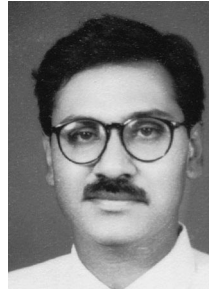
Anshuman Khare works as a Research Scientist for the University Grants Commission, India and is placed at the Motilal Nehru Institute of Research and Business Administration, University of Allahabad, India. He teaches Quantitative Analysis and Business Policy. His research interests are Japanese Business philosophy and responsible manufacturing. He has done his post-doctoral research at Ryukoku University, Kyoto, Japan on a Japanese Government Scholarship (1995–1997). He has also delivered lectures at the Kyoto Institute of Technology, Ryukoku University, Kyoto, and Kansai Gaidai, Osaka, Japan. Presently he is a Research Fellow of the Alexander von Humboldt Stiftung at the Johannes-Gutenberg Universität Mainz, Mainz, Germany and works on environment related techno-managerial issues in automobile manufacturing. He has published three books and over 100 research papers and articles in India and abroad.